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### PROBLEMS OF THE ATMOSPHERE.

By Prof. JAMES DEWAR.

In the Proceedings of the Royal Institution of Great Britain, vol. 17, part 1, No. 96, November, 1903, p. 223, Prof. James Dewar, after describing his method for removing the more condensable constituents of the atmosphere and his process of analyzing the resulting mixture of rare gases, continues as follows:

These experiments prove that air<sup>1</sup> contains as a minimum 1/362,000 of its volume of helium, about 1/70,000 of neon, and not more than 1/100,000 of free hydrogen. \* \* \*

The spectroscopic examination of these gases throws new light upon the question of the aurora and the nature of the upper air. On passing electric discharges through tubes containing the most volatile of the atmospheric gases, they glow with a bright orange light, which is especially marked at the negative pole. The spectroscope shows that this light consists, in the visible part of the spectrum, chiefly of a succession of strong rays in the red, orange, and yellow, attributed to hydrogen, helium, and neon. Besides these a vast number of rays, generally less brilliant, are distributed through the whole length of the visible spectrum. The greater part of these rays are as yet of unknown origin. The violet and ultra-violet part of the spectrum rivals in strength that of the red and yellow rays. As these gases probably include some of the gases that pervade interplanetary space, search was made for the prominent nebular, coronal, and auroral lines.

No definite lines agreeing with the nebular spectrum could be found, but many lines occurred closely coincident with the coronal and auroral spectrum. But before discussing the spectroscopic problem, it will be necessary to consider the nature and condition of the upper air.

According to the old law of Dalton, supported by the modern dynamical theory of gases, each constituent of the atmosphere while acted upon by the force of gravity forms a separate atmosphere, completely independent, except as to temperature, of the others, and the relations between the common temperature and the pressure and altitude for each specific atmosphere can be definitely expressed.

If we assume the altitude and temperature known, then the pressure can be ascertained for the same height in the case of

each of the gaseous constituents, and in this way the percentage composition of the atmosphere at that place may be deduced.

Suppose we start with a surface atmosphere having the composition of our air, only containing 2/10,000 of hydrogen; then, at 37 miles, if a sample could be procured for analysis, we believe that it would be found to contain 12 per cent of hydrogen, and only 10 per cent of oxygen. The carbonic acid practically disappears; and by the time we reach 47 miles, where the temperature is minus 132°, assuming a gradient of 3.2° per mile, the nitrogen and oxygen have so thinned out that the only constituent of the upper air which is left is hydrogen. If the gradient of temperature were doubled the elimination of the nitrogen and oxygen would take place by the time 37 miles was reached, with a temperature of minus 220°.

The theoretical distribution of the chief components of our atmosphere, on the assumption of steady equilibrium, is graphically represented in figs. 1 and 2. In these diagrams nitrogen is represented by the horizontal hachure, oxygen by the diagonal hachure, hydrogen by the stippling, argon by the blank white space, and carbonic acid by black. A horizontal line drawn across the diagram at any height marked in kilometers (0.62 mile) shows the percentage by volume of the constituents at that elevation, by the respective lengths within the hachures of the individual constituents. The results of Hinrich's calculations which involve no consideration of the effects of temperature, are represented in fig. 1, and those of Ferrel, who assumes a temperature gradient of 4° per kilometer throughout the upper air, in fig. 2. The higher the assumed temperature gradient the lower the elevation at which the nitrogen and oxygen are eliminated and the true hydrogen atmosphere begins. The elevations marked *A, B, C, D*, in fig. 2, refer to the respective gradients of 4°, 3°, 2°, and 1°, per kilometer, and mark the end of the nitrogen and the beginning of the true hydrogen atmosphere. The position *A* corresponds to 60 kilometers and a temperature of -220°; *B*, to 67 kilometers and -181° C.; *C*, to 76 kilometers and -132°; and *D*, to 87 kilometers and -67°.

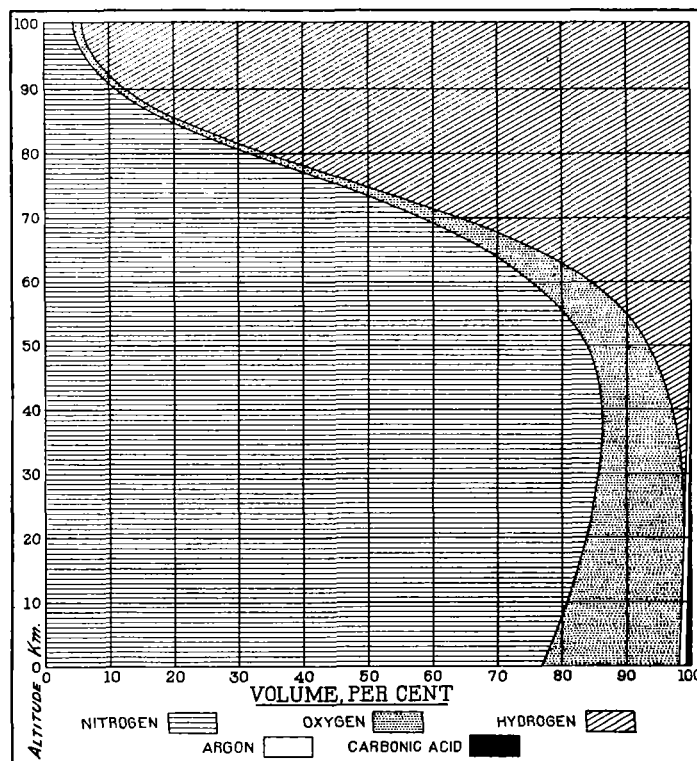


FIG. 1.—Distribution of the atmospheric gases, Hinrich's formula.

<sup>1</sup> We ought rather to say the air of London.—ED.

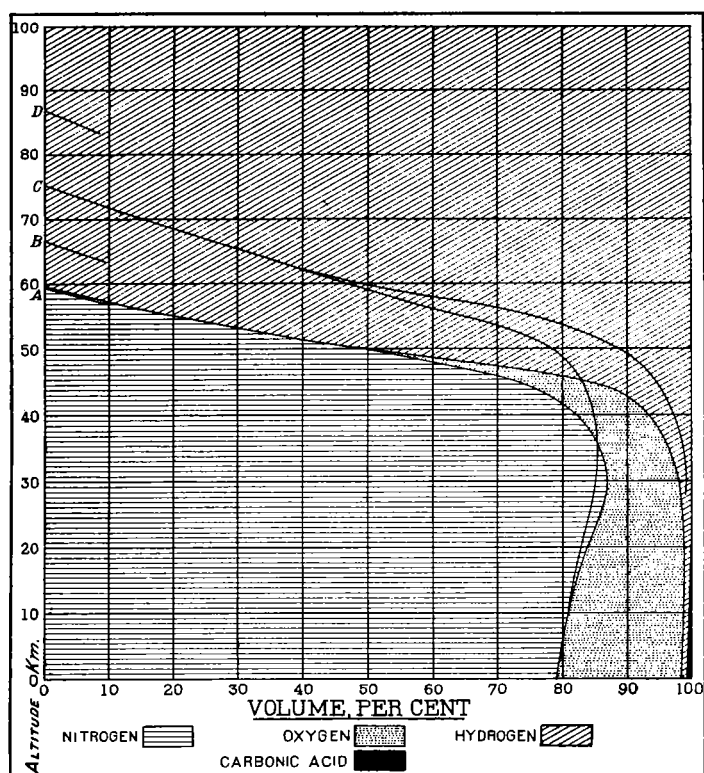


FIG. 2.—Distribution of the atmospheric gases, Ferrel's formula.

On any of these temperature gradient hypotheses it appears that practically above 56 miles the atmosphere would be substantially composed of hydrogen. If helium and neon had been included in the calculations, they would have been found concentrated at high elevation between the regions occupied respectively by the hydrogen and the nitrogen in the diagrams. If the temperature is taken as constant, fig. 2 shows that at an elevation of some 62 miles the composition of a sample of air, if it could be secured, would be 95.1 per cent of hydrogen, 4.6 per cent of nitrogen, and 0.3 per cent of oxygen.

The permanence of the composition of the air at the highest altitudes, as deduced from the basis of the dynamical theory of gases, has been discussed by Stoney, Bryan, and others.<sup>2</sup> It would appear that there is a consensus of opinion that the rate at which gases like hydrogen and helium could escape from the earth's atmosphere would be excessively slow. Considering that to compensate any such loss the same gases are being supplied by actions taking place in the crust of the earth, we may safely regard them as necessarily permanent constituents of the upper air.

The temperature at the elevations we have been discussing would not be sufficient to cause any liquefaction of the nitrogen and oxygen, on account of the pressure being so low. If we assume the mean temperature as about the boiling point of oxygen, then a considerable amount of the carbonic acid must solidify as a mist, if the air from a lower level be cooled to this temperature; and the same result might take place with other gases of relatively small volatility which occur in the air. The temperature of the upper air must be above that on the vapor-pressure curve corresponding to the barometric pressure at the locality, otherwise liquid condensation must take place. In other words, the temperature must be above the dew-point of air at that place. At very high elevations, on any reasonable assumption of temperature distribution, we inevitably reach a temperature where the air would condense, just as Fourier and Poisson supposed it would, unless the tem-

perature is arrested in some way from approaching the zero.

Both ultra-violet absorption and the prevalence of electric storms may have something to do with the maintenance of a higher mean temperature than we should anticipate, following the deductions of our assumed formulas for temperature decrements. The whole mass of the air above 40 miles is not more than  $1/700$  part of the total mass of the atmosphere, so that any rain or snow of liquid or solid air, if it did occur, would necessarily be of a very tenuous description. In any case, the dense gases tend to accumulate in the lower strata, and the lighter ones to predominate at the higher altitudes, always assuming a steady state of equilibrium has been reached.

It must be observed, however, that a sample of air taken at an elevation of 9 miles has shown no difference in composition from that at the ground, whereas, according to our hypothesis, the oxygen ought to have been diminished to 17 per cent and the carbonic acid should also have become much less. This can only be explained by assuming that a large intermixture of the different layers of the atmosphere is still taking place at this elevation. This is confirmed by a study of the motions of clouds about six miles high, which reveals an average velocity of the air currents of some 70 miles per hour; such violent winds must be the means of causing the intermingling of different atmospheric strata. Some clouds, however, during hot and thundery weather, have been seen to reach an elevation of 17 miles, so that we have direct proof that on occasion the lower layers of atmosphere are carried to a great elevation.

The existence of an atmosphere at more than a hundred miles above the surface of the earth is revealed to us by the phenomenon of twilight and the luminosity of meteors and fireballs. When we can take photographs of meteoric spectra, a great deal may be learned about the composition of the upper air. In the meantime Pickering's solitary spectrum of a meteor reveals an atmosphere of hydrogen and helium, and so far this is a corroboration of the doctrine we have been discussing. It has long been recognized that the aurora is the result of electric discharges within the limits of the earth's atmosphere, but it was difficult to understand why its spectrum should be so entirely different from anything which could be produced artificially by electric discharges through rarefied air at the surface of the earth. Rand Capron, in 1879, after collecting all the recorded observations, was able to enumerate no more than nine auroral rays, of which but one could with any probability be identified with rays emitted by atmospheric air under electric discharge. Vogel attributed this want of agreement between nature and experiment, in a vague way, to difference of temperature and pressure; and Zöllner thought the auroral spectrum to be one of a different order, in the sense in which the line and band spectrum of nitrogen are said to be of different orders.

Such statements were merely confessions of ignorance. But since that time observations of the spectra of auroras have been greatly multiplied, chiefly through the Swedish and Danish polar expeditions. The spectrum recorded on the ultra-violet side has been greatly extended by the use of photography, so that, in a recent discussion of results, M. Henri Stassano is able to enumerate upward of 100 auroral rays, of which the wave length is more or less approximately known. Of this large number of rays he is able to identify, within the probable limits of errors of observation, about two-thirds as rays which Professor Liveing and myself have observed to be emitted by the most volatile gases of atmospheric air unliquefiable at the temperature of liquid hydrogen. Most of the remainder he ascribes to argon, and some might, with more probability, have been identified with krypton or xenon.

The rosy tint often seen in auroras, particularly in the streamers, appears to be due mainly to neon, of which the spectrum is remarkably rich in red and orange rays. One or

<sup>2</sup> See also S. R. Cook in Monthly Weather Review for August, 1902, pp. 401-407, and September, 1902, p. 405.—Ed.

two neon rays are amongst those most frequently observed, while the red ray of hydrogen and one red ray of krypton have been noticed only once. The predominance of neon is not surprising, seeing that from its relatively greater proportion in air and its low density it must tend to concentrate at higher elevations.

So large a number of probable identifications warrants the belief that we may yet be able to reproduce in our laboratories the auroral spectrum in its entirety. It is true that we have still to account for the appearance of some and the absence of other rays of the newly discovered gases, which, in the way we stimulate them, appear to be equally brilliant, and for the absence, with one doubtful exception, of all the rays of nitrogen. If we can not give the reason of this it is because we do not know the mechanism of luminescence, nor even when the particles that carry the electricity are themselves luminous, or whether they only produce stresses causing other particles which encounter them to vibrate; yet we are certain that an electric discharge in a highly rarefied mixture of gases lights one element and not another in a way which, to our ignorance, seems capricious.

The Swedish North Polar Expedition concluded from a great number of trigonometrical measurements that the average above the ground of the base of the aurora was 50 kilometers (34 miles) at Cape Thorsden, Spitzbergen;<sup>3</sup> at this height the pressure of the nitrogen of the atmosphere would be only about one-tenth of a millimeter, and Moissan and Deslandres have found that in atmospheric air at pressures less than one millimeter the rays of nitrogen and oxygen fade and are replaced by those of argon and by five new rays which Stassano identifies with rays of the more volatile gases measured by us. Also, Collie and Ramsay's observations on the distance to which electrical discharges of equal potential traverse different gases throw much light on the question. They find that, while for helium and neon this distance is from 250 to 300 millimeters, for argon it is 45½ millimeters, for hydrogen it is 39 millimeters, and for air and oxygen still less.

This indicates that a good deal depends on the very constitution of the gases themselves, and certainly helps us to understand why neon and argon, which exist in the atmosphere in larger proportions than helium, krypton, or xenon, should make their appearance in the spectrum of auroras almost to the exclusion of nitrogen and oxygen.

How much depends not only on the constitution and it may be temperature of the gases, but also on the character of the electric discharge, is evident from the difference between the spectra at the cathode and anode in different gases, notably in nitrogen and argon, and not less remarkably in the more volatile compounds of the atmosphere.

Without stopping to discuss that question, it is certain that changes in the character of the electric discharge produce definite changes in the spectra excited by them. It has long been known that in many spectra the rays which are inconspicuous with an uncondensed electric discharge become very pronounced when a Leyden jar is in the circuit. This used to be ascribed to a higher temperature in this condensed spark, though measurements of that temperature have not borne out the explanation. Schuster and Hemsalech have shown that these changes of spectra are in part due to the oscillatory character of the condenser discharge, which may be enhanced by self-induction, and the corresponding change of spectrum thereby made more pronounced.

If we turn to the question what is the cause of the electric discharges which are generally believed to occasion auroras, but of which little more has hitherto been known than that they are connected with sun spots and solar eruptions, recent studies of electric discharges in high vacua, with which the

names of Crookes, Röntgen, Lenard, and J. J. Thomson will always be associated, have opened the way for Arrhenius to suggest a definite and rational answer. He points out that the frequent disturbances which we know to occur in the sun must cause electrical discharges in the sun's atmosphere far exceeding any that occur in that of the earth. These will be attended with an ionisation of the gases, and the negative ions will stream away through the outer atmosphere of the sun into interplanetary space, becoming, as Wilson has shown, nuclei of aggregation of condensable vapors and cosmic dust. The liquid and solid particles thus formed will be of various sizes; the larger will gravitate back to the sun, while those with diameters less than one and a half thousandths of a millimeter, but nevertheless greater than a wave length of light, will in accordance with Clerk-Maxwell's electromagnetic theory, be driven away from the sun by the incidence of the solar rays upon them, with velocities that may become enormous, until they meet other celestial bodies, or increase their dimensions by picking up more cosmic dust, or diminish them by evaporation. The earth will catch its share of such particles on the side that is turned toward the sun, and its upper atmosphere will thereby become negatively electrified until the potential of the charge reaches such a point that a discharge occurs, which will be repeated as more charged particles reach the earth.

#### TORNADO AT MOUNDVILLE, ALA.

By FRANK P. CHAFFEE, Section Director, Montgomery, Ala., dated February 8, 1904.

The tornado at Moundville, Ala., on January 22, 1904, was first felt 2 miles southwest of Moundville, Hale County, Ala., at about 1:20 a. m., seventy-fifth meridian time. The previous evening was warm, with moderately heavy rains at intervals, and the wind blowing in fitful, heavy gusts from the southeast and south. The tornado was most destructive at Moundville, at which place nearly every building was demolished, several freight cars destroyed, 36 persons killed, and 80 injured out of a population of about 300.

The path of the storm extended from southwest to northeast; it was about 5 miles in length and 200 yards wide at the point of greatest destruction. It was accompanied with a funnel-shaped cloud, which had a phosphorescent glow and emitted blinding flashes of lightning, and from which was heard a loud, rumbling noise, resembling that caused by a number of rapidly-moving freight trains. The tornado lasted but a few minutes, and there seems to have been no evidence of its having any bounding motion.

A large, well-constructed railroad warehouse, 40 other frame buildings, a large water tank, and several freight cars were literally torn to pieces. It is reported that some of the timbers of the structures destroyed were twisted and splintered, and that the ground along the path of the storm was swept bare of vegetation. Bales of cotton, stored in the warehouse mentioned above, were torn open and the cotton scattered for some distance. While the destructive force of the storm did not extend over 5 miles northeast of Moundville, debris from that place is reported to have been carried as far as Tidewater, a village in Tuscaloosa County, about 19 miles to the northeast. Effort was made to ascertain the direction of the whirling motion of the storm, but reports as to this are too conflicting to be of value. The storm occurred at such an hour that few persons saw the funnel-shaped cloud or noted its movements.

At Tuscaloosa, about 15 miles north, and at Greensboro, about 24 miles south of Moundville, there were much lightning, moderately heavy rains, and high, but not destructive, winds.

At Hull, a small town about 5 miles northeast of Moundville, a large lumber mill was destroyed.

At Birmingham, about 60 miles northeast, the wind was also destructive, demolishing 35 cabins in the northern suburbs of that city, though causing no loss of life. The highest regis-

<sup>3</sup>This conclusion was afterwards shown to have no logical basis. See *Terrestrial Magnetism*. 1898. Vol. III, pp. 152-154 and 164-169.—Ed.